Neural Network-Based Hyperspectral Algorithms

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LONG-TERM GOAL

Our long term goal is to contribute to our understanding of numerical methods for inversion of remotely sensed data, and to adapt these methods to the retrieval of water parameters from hyperspectral observations of complex coastal environments.

OBJECTIVES

We wish to use the neural network paradigm to establish relationships between water-leaving spectral radiance in the 400 to 750 nm spectral range, and water parameters such as depth, bottom material, and inherent optical properties (IOP) of the water column. These relationships will be exploited to form algorithms for retrieval of these parameters from remotely sensed multi- or hyperspectral data.

APPROACH

Field observations of inherent optical properties (HiSTAR and AC9) will be combined with radiative transfer models (HYDROLIGHT and MODTRAN) to produce simulated spectral water-leaving radiance and remote sensing reflectance data which will form the basis for this study. We will use neural networks to establish nonlinear inverse relationships between spectral radiance and water parameters of interest. Multivariate statistical methods will be used to characterize these relationships in terms of true dimensionality of the hyperspectral data sets, optimal selection of wavelength subsets, and expected accuracy of parameter estimates based on these inverse relationships. The end product of this research will be prototype algorithms, with associated error bars, for retrieval of IOPs, water depth, and bottom type from remotely sensed multi- or hyperspectral imagery. We have demonstrated the use of neural networks for bathymetry retrieval for specific sites (Sandidge and Holyer, 1998). The major unanswered scientific question is the universality of the inverse relationships developed here. In other words, will it be possible to develop algorithms that can be applied to any coastal marine environment or will it be necessary to develop regional/seasonal specific algorithms? We intend to provide new insight into this question, so field data from many diverse environments is essential to our approach. We will not collect field data directly, but will rely on other investigators in the HyCODE, CoBOP, ECOHAB, and NRL programs to meet our data needs.

WORK COMPLETED

HiSTAR data from the experiment on the West Florida Shelf in October of 1998 was to provide the initial hyperspectral IOP data for our study. The HiSTAR instrument was shown to have serious problems during this deployment and the data was deemed unusable. Since our work hinged on this

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data set, we undertook the unexpected task of attempting to salvage the HiSTAR data. Since the AC9 had been deployed simultaneously with the HiSTAR we developed a method to use the more reliable and better understood AC9 to perform a vicarious calibration of the HiSTAR. We used the AC9 to adjust the overall level and shape of the HiSTAR curves for absorption, a, and total attenuation coefficient, c, while preserving the spectral fine structure recorded by the HiSTAR. A total of 53 of the 58 available HiSTAR casts were correctable by this method.

The corrected HiSTAR depth profiles of spectral a and c were input to the HYDROLIGHT radiative transfer model to generate spectral curves of water-leaving radiance and remote sensing reflectance. Over 2100 HYDROLIGHT runs have been performed to date using the 53 HiSTAR casts and various combinations of water depth, bottom type, sun angle, wind speed, etc. Corrected HiSTAR data and HYDROLIGHT output files are now available to other investigators.

We have developed software to perform a query on the HYDROLIGHT output files and extract "training sets" that meet specific requirements related to parameters associated with the HYDROLIGHT computations. (For example, we can produce a training set of all cases where the bottom is coral sand and the depth is less than 10 meters.) The training sets thus produced become the basis for forming neural network models of radiance-to-parameter inverse relationships.

Multivariate statistical methods (principal components analysis) have been applied to determine the true dimensionality of the optical data from the West Florida Shelf and to indicate the best wavelengths for retrieval of bathymetry in this region.

Initial neural models have been developed which show that bathymetry retrievals with useful accuracy (see results section) are possible without *a priori* knowledge of water IOPs or bottom type. This is the first information related to the universality question.

RESULTS

A data set consisting of 1961 cases where bottom reflectance was included in the HYDROLIGHT run and the depth was less than 20 m was subjected to principal components analysis. Table 1 shows the amount of variance associated with each of the first five principle components. The table shows that 99% of the variance in this data is contained in only 3 dimensions even though the HYDROLIGHT output is 70-dimensional. (The HYDROLIGHT calculations were performed at 70 wavelengths ranging from 402.5 to 747.5 nm on 5nm increments.) This is a somewhat surprising result since the data includes four bottom types (coral sand, and red, green, and brown algae) and water types ranging from the outer shelf to near the beach. The low dimensionality of the data bears upon issues of data compression for transmission and storage of the data as well as upon computational demands for reducing the data to geophysical parameters. Although additional data from other locations will undoubtedly expand the dimensionality somewhat, early indications are that we will be dealing with a relatively low-dimensional problem.

Table 1. Summary of Principal Components Analysis

Principal Component Number	Variance Captured (% of total)	Cumulative Variance (%)
1	86.53	86.53
2	8.80	95.34
3	3.66	99.00
4	0.42	99.42
5	0.28	99.69

A neural network was trained on the HYDROLIGHT data set to produce estimates of water depth given the first 5 principal components of spectral remote sensing reflectance as an input. All bottom types, water types, and sun angles were included but the neural network had no knowledge of the values of these variables for a given sample. The neural network converged to a solution which resulted in an RMS error in the depth estimates of 0.64 m overall with an RMS error of 0.31 m over the range 0 to 4 m depth, which is the most important for Navy purposes. Figure 1 is a scatter plot of the errors in the depth estimates. There are no significant “outliers” indicating a well-behaved relationship between optical spectral reflectance and water depth. Useful results are obtained over all bottom types and through all water types contained within the West Florida Shelf data which is taken as evidence in support of the existence of universal algorithms.

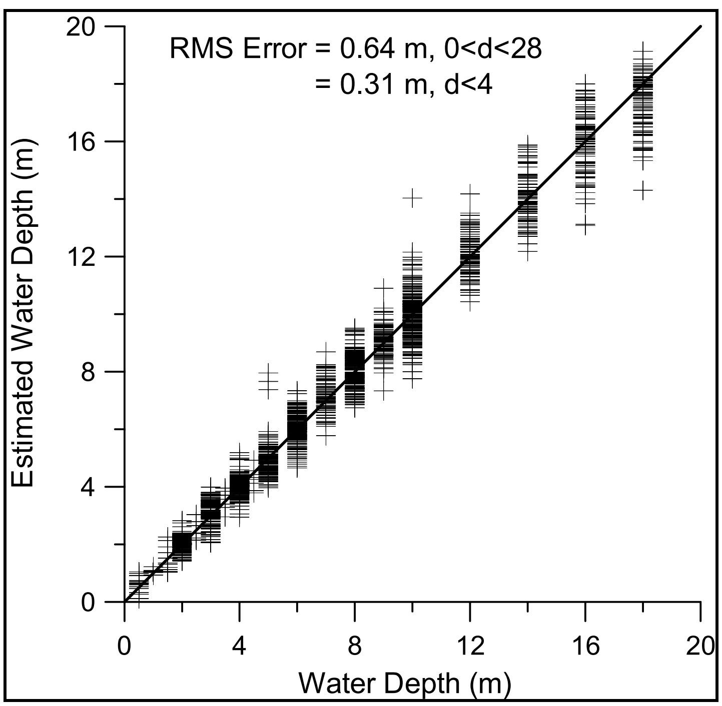

Figure 1. Scatter plot of errors in neural network estimates of water depth.

IMPACT/APPLICATION

We have conducted the first steps of research leading toward universal algorithms for retrieval of water parameters from hyperspectral observations of ocean radiance. The work is still preliminary (we have not yet addressed retrieval of IOPs, bottom type classification, or effects of atmospheric radiative transfer), but present indications are that our approach will lead to useful retrievals of the desired parameters in midst of coastal ocean complexity. This work enhances the probability that algorithms can be available to Navy operational commands shortly after the launch of the Navy Earth Map Observer satellite.

TRANSITIONS

Corrected HiSTAR data and a large set of HYDROLIGHT output files are available to other investigators.

RELATED PROJECTS

Work has been done in conjunction with NRL investigators at Stennis Space Center. Specifically, NRL has conducted bathymetry surveys to provide ground truth for our bathymetry algorithms and has collected HiSTAR and AC9 data used in our study. NRL investigators have also participated with us in neural network studies. In particular a hybrid deterministic/statistical training algorithm combining back propagation and simulated annealing developed by Dr. Walt Smith at NRL has been applied to the data that we have generated.

REFERENCES

Sandidge, J.C. and R.J. Holyer, 1998. "Coastal Bathymetry from Hyperspectral Observations of Water Radiance," *Remote Sens. Environ.*, 65:341-352.